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CRANFIELD INSTITUTE OF TECHNOLOGY

RADIAL INFLOW TURBINE STUDY

SIXTH INTERIM REPORT

by

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The radial inflow turbine is a primary component used both in small gas turbines and turbochargers. Better understanding of the flow processes occurring within the small passages of the machine could well result in the improved design of units. As most of the detailed aerodynamics is still ill-defined, a joint research project with the objective of improving our understanding has been instigated by Cranfield, the US Army and Turbomach (San Diego).

This document gives the sixth report on the project. It describes progress and measurements taken downstream of the rotor.

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PROGRESS REPORT

PERIOD: 1.7.91 TO 31.12.91

Our previous report (June 1991) described attempts to take laser measurements at different positions downstream the turbine rotor for various values of pressure ratio. A problem arose, however, in that immediately after starting the rig, the turbine outlet temperature went sub-zero ($\approx$ -15°C) causing an ice layer to form on the optical glass window prohibiting any laser anemometry measurements.

The situation was improved by allowing the rig to 'warm up' (heat soak) for at least half an hour which raised the turbine outlet temperature to about 10°C and for lower pressure ratios (2.0, 2.5) where some laser results could be obtained. For higher values of pressure ratio (3.0 and above) the situation deteriorated and again no laser results could be obtained. In an attempt to overcome the problem some air was bled through a tube from the turbine inlet to keep the optical window warm. This technique worked reasonably and prevented water droplets appearing on the glass surface but the system was cumbersome and the 'warm up' times for the rig permitted the windows to become dirty enough to prohibit measurements.

Another option to eliminate this problem was to heat the air entering the turbine. The present experimental arrangement of the rig has a combustor situated nearly two meters upstream of the turbine inlet but this was thought to be too uncontrolable and would dirty the measurement windows with soot.

Installation of electrical heaters was therefore undertaken. Eighteen heating elements (2.25 KW per element) were installed far enough from the turbine inlet to cause negligible disturbance to the flow. A considerable amount of time was consumed in selecting the heating elements, machining the air ducts and installation of the heating elements. Special arrangements have been provided to prevent overheating in case of lower mass flow. Heating elements were arranged into three groups consisting of 9, 6 and 3 elements each. This arrangement was thought advantageous in providing some control over the air temperature.

The rig was run after these modifications and very satisfactory results were obtained. It is now possible to keep the turbine inlet temperature high enough (≈ 100°C) to avoid any condensation on the optical windows. The successful completion of the task made it possible to take laser measurements at both the required downstream positions marked as window A and B in Figure 1.

In order to compare the laser results with some conventional measurements, a Cobra yawmeter probe has been used. It was necessary to calibrate the probe before its use in the actual flow situation. This was done by using a calibration tunnel facility available in the Department. The probe was rotated from -40° to +40°. Two static and one total pressure readings were used to calculate C_s (static coefficient), C_T (total coefficient) and C_W (yaw angle coefficient). Data was obtained at various flow settings and presented as shown in Figure 2. An offset of 2.8° was calculated from the graph. This offset value was added to all the flow angles measured by the probe in the test arrangement.

<u>**Laser and Cobra Probe Measurements at Window A**</u>

Fifteen radial stations were chosen separated by a distance of approximately .125 inch (≈ 3.2mm). The radius at window A was found to be approximately 49.32mm and the last laser measurement was made at a position 46.16mm away from the centre (i.e. 3.2mm away from the duct wall). Running conditions for laser and Cobra probe measurements were as follows:-

$$\frac{U}{V_o} = .64$$

$$PR = 3.0$$

Figure 3 shows the variation in air swirl angle with radius for both laser anemometer and the Cobra probe. A graph shows that results from both instruments follow the same trend except that the Cobra probe readings are a bit lower. The difference becomes insignificantly small as the radius increases. Most notably these results indicate a core of counter-rotating flow probably eminating from the turbine hub. Velocity at all these stations was also measured by both instruments and results are shown in

Figure 4. This figure shows that the Cobra probe gives a velocity lower than that measured by laser techniques and this difference increases as the radius becomes greater than 35mm. The reason for this difference is possibly interaction of the Cobra sensor with the wall (wall effect). The laser anemometer is a non-intrusive technique and is felt to be more accurate.

Measurements at Window B

The running conditions for laser and pressure probe measurements were the same as described above, i.e.

$$\frac{U}{V_o} = .64$$

$$PR = 3.0$$

Ten radial stations with a separation of 3.2mm were chosen in this case as the radius of the duct at this position is approximately 38mm. Figures 5 and 6 give air swirl angle and velocity for all these stations. Cobra probe readings are lower. In both graphs, laser and pressure probe measurements show the same trend. In Figure 6 the pressure probe gave very unstable results for the first two stations. Again the presence of a counter-rotating core will be noted. Discussion of these results will follow in the final report.

Work in Progress

Other running conditions at window B have successfully been obtained by throttling the compressor outlet in small steps to obtain different values of U/V_o, i.e.

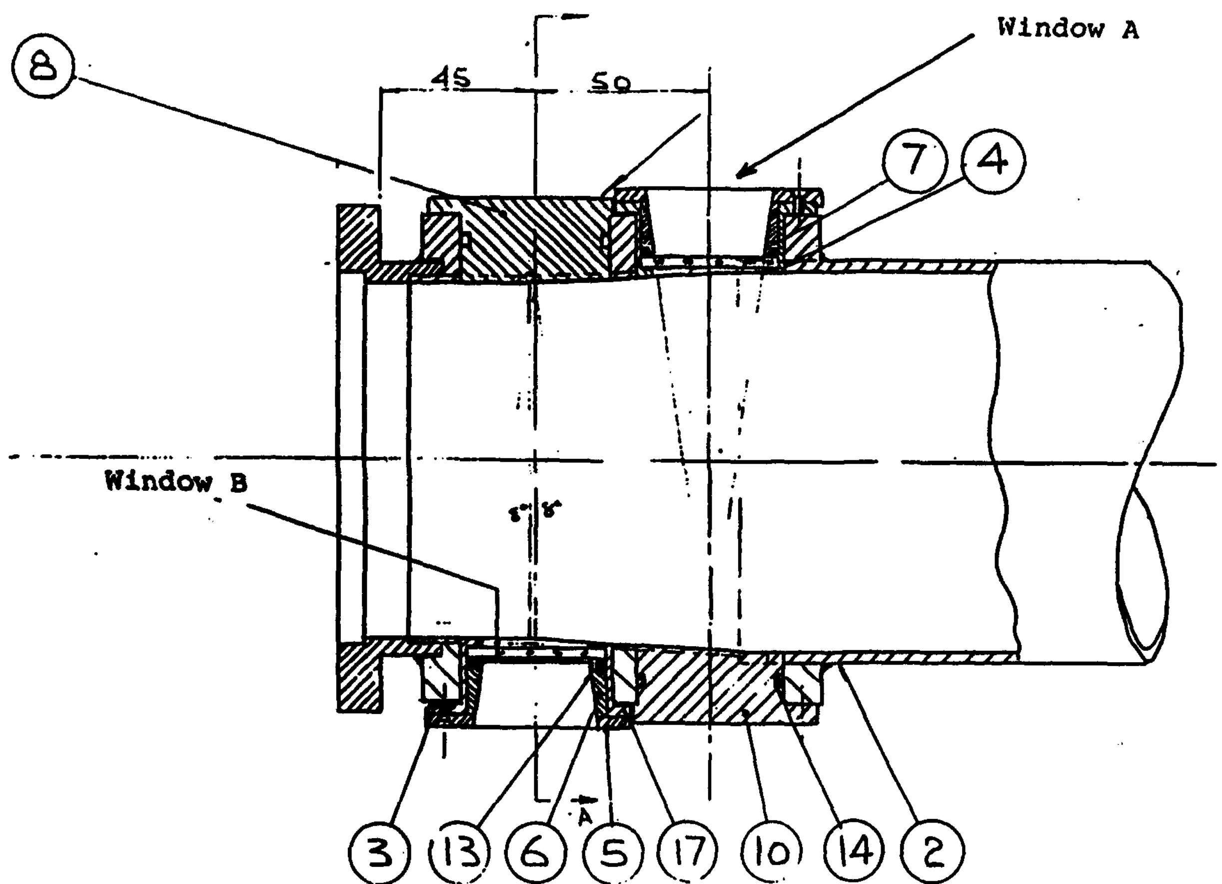
$$\frac{U}{V_o} = 0.64, 0.68, 0.70, 0.72 \quad \text{for} \quad PR = 3.0$$

Laser and pressure probe work is in progress and results are being collected for all these running conditions. Other conditions under consideration are:

$$\frac{U}{V_o} = 0.64,\ 0.68,\ 0.70,\ 0.72 \quad \text{for} \quad PR = 3.5$$

Measurements at Window A will also be made at these conditions.

Whilst the above measurements have been undertaken several schemes and sketches have been developed to machine the assembly providing optical access to the inlet of the turbine rotor. The drawing work is in progress and the machining of the assembly will start as soon as the laser work is finished at both windows downstream of the rotor.



Note ; In practice both windows are on the same side.

FIG 1 ; WINDOWS FOR OPTICAL ACCESS

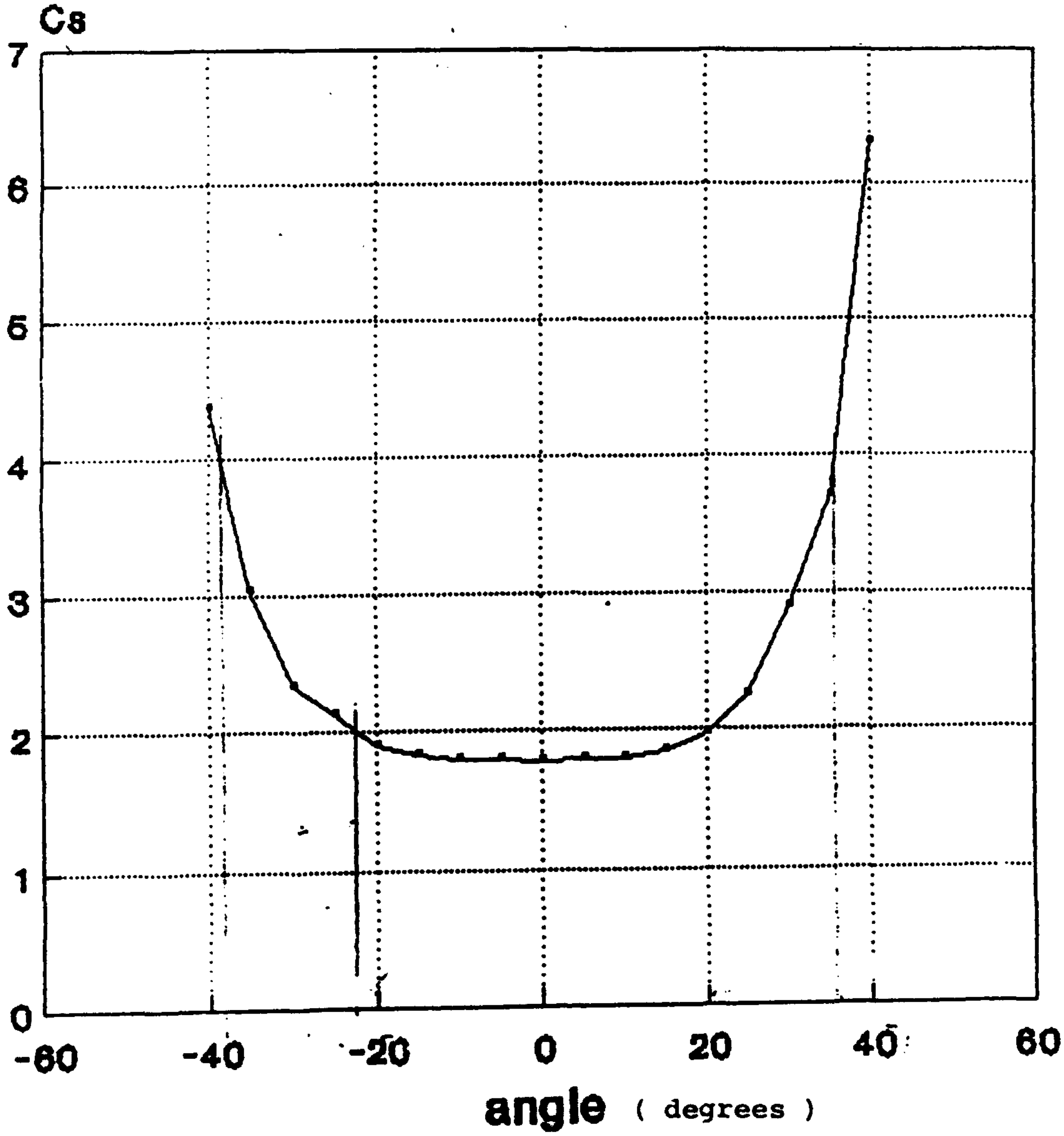


FIGURE 2 : Cobra probe calibration

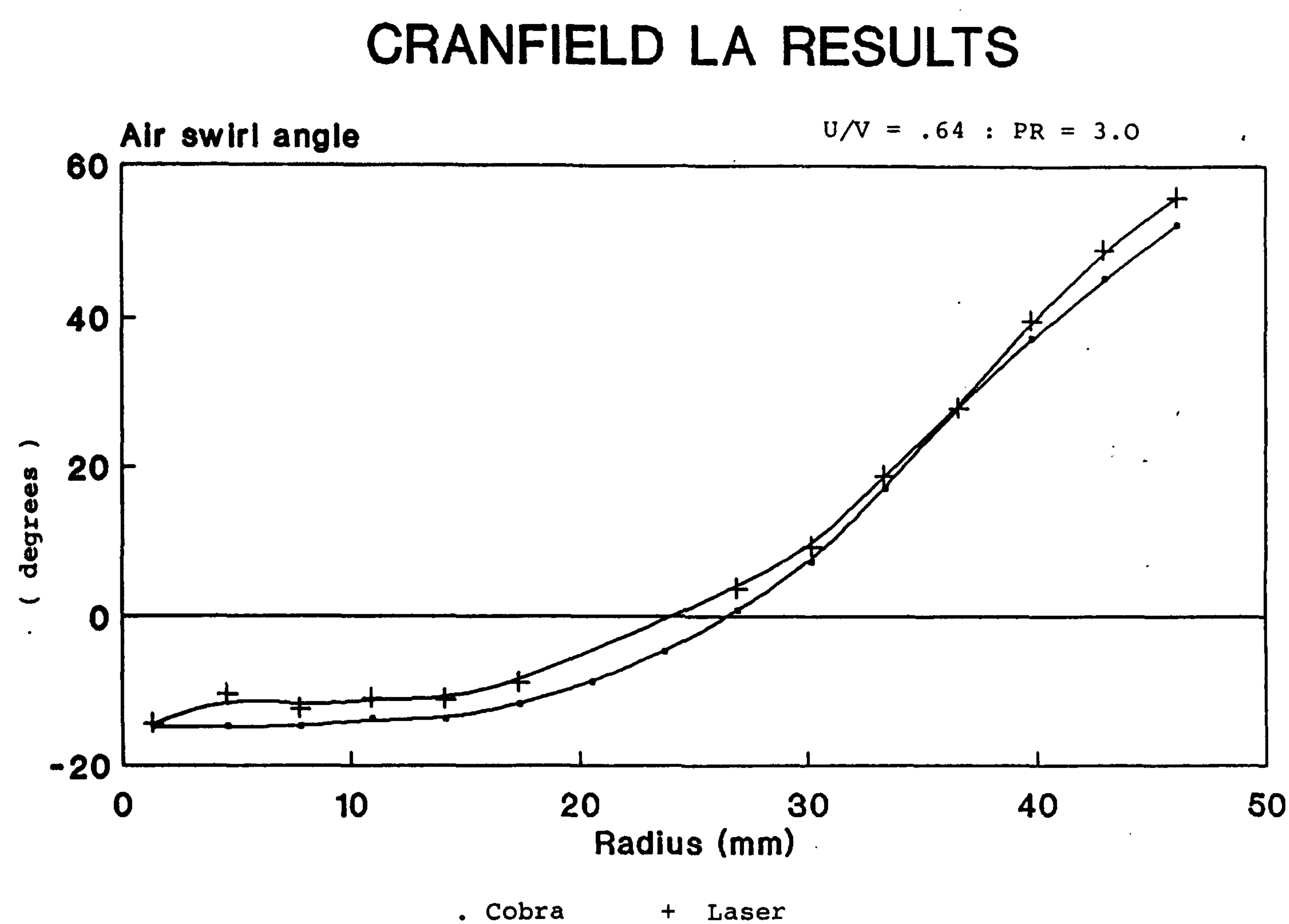


FIGURE 3 : Laser anemometry results at window A

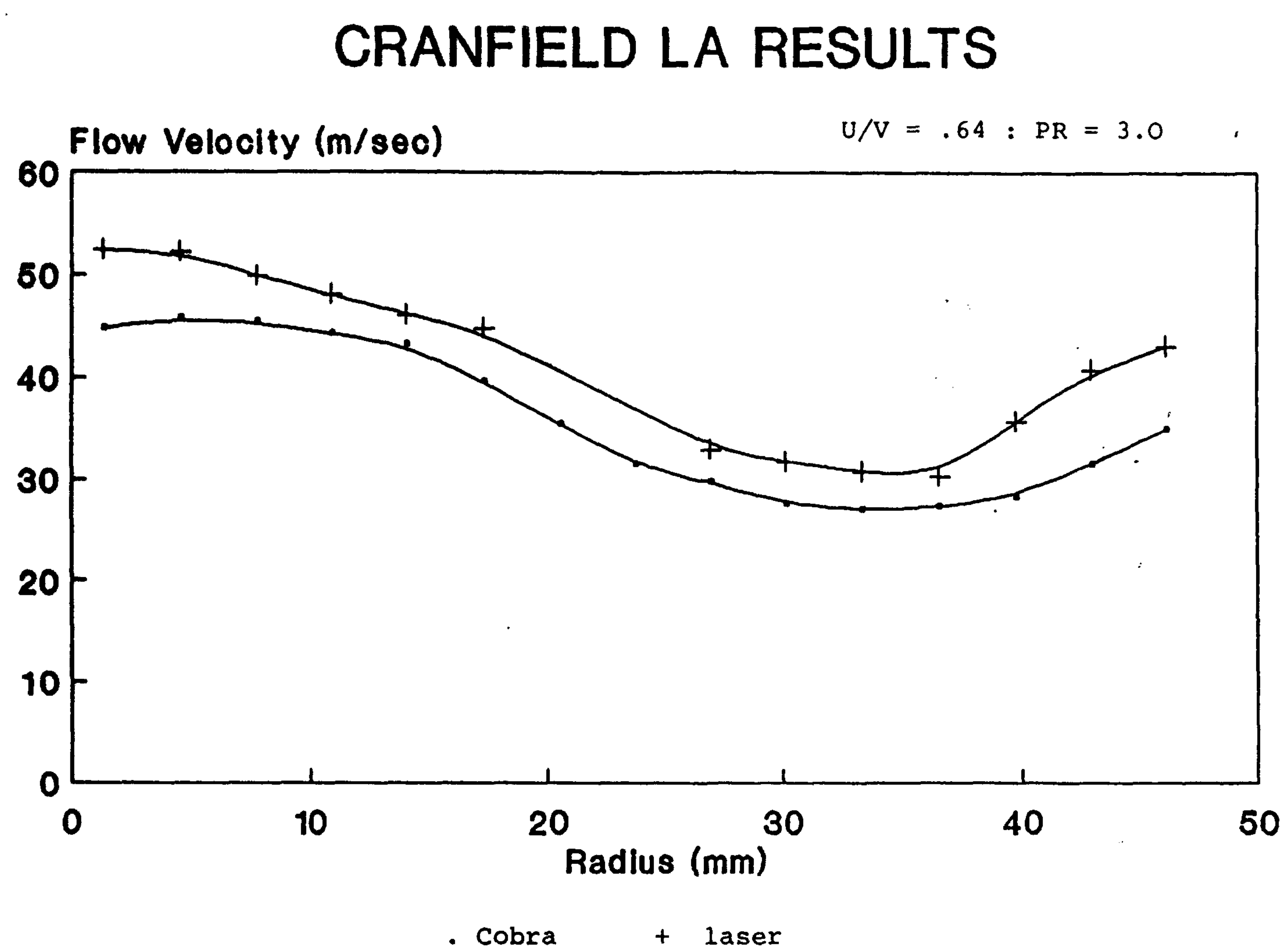


FIGURE 4 : Laser anemometry results at window A

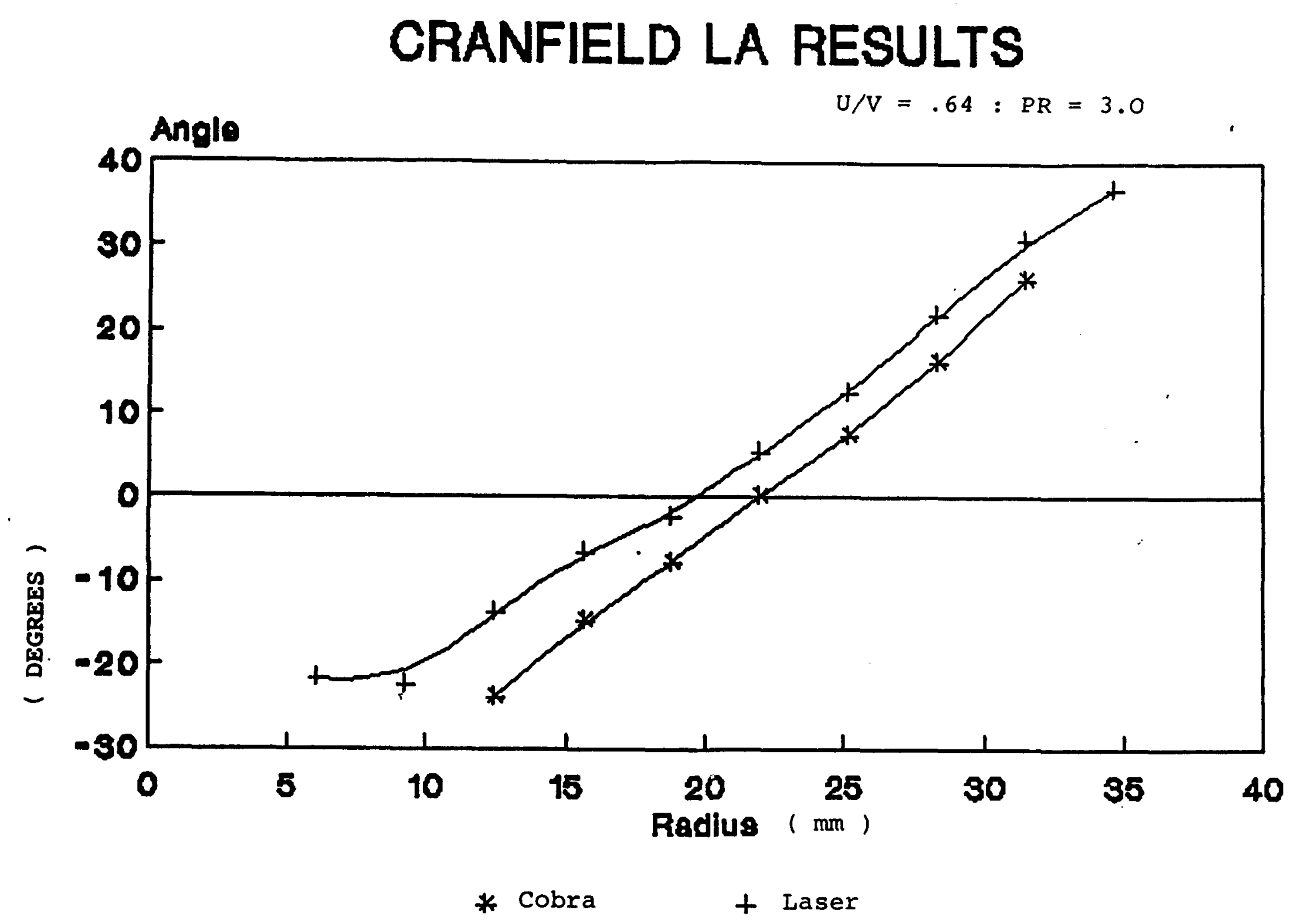


FIGURE 5 : Laser anemometry results at window B

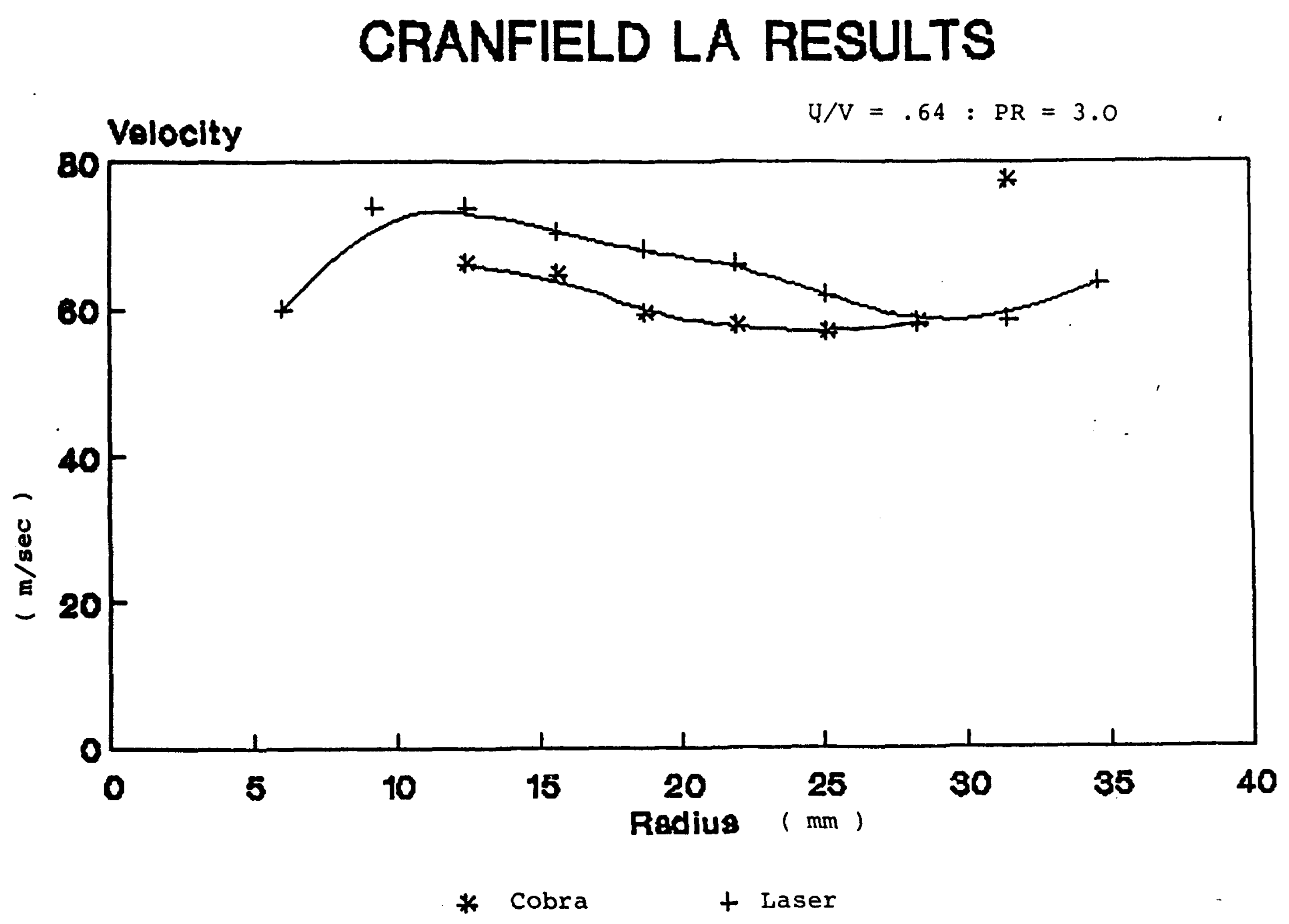


FIGURE 6 : Laser anemometry results at window B